

IMPACT OF CLIMATE CHANGE ON COCONUT AND IDENTIFICATION OF ADAPTATION MEASURES WITH SPECIAL EMPHASIS ON REPRODUCTIVE DEVELOPMENT

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ABSTRACT

*The study investigated the impacts of heat and drought stress on reproductive performance of coconut, its difference among the cultivars and the capacity of coconut-based mixed cropping systems in improving the micro-climatic conditions and reproductive performance of coconut plantations. When coconut plantations (Tall x Tall) were naturally exposed to heat stress (without water stress), the quality of pollen and production of female flowers were not affected by heat stress and high VPD, but the fruit set was significantly reduced during the period of high temperature ($T_{max} > 35^{\circ}\text{C}$) and VPD (> 2.5 KPa). When coconut palms were naturally exposed to long dry spells associated with heat stress, fruit set/palm/month showed a strong negative relationship with number of high temperature days ($T_{max} \geq 33^{\circ}\text{C}$) during first three months of inflorescence opening. The cultivar differences were observed for minimum (T_{min}), optimum (T_{opt}) and maximum (T_{max}) for *in vitro* pollen germination (%PG). Air temperature at canopy level, soil temperature, soil moisture content, rate of photosynthesis and fruit set of coconut palms were modified by coconut-based mixed cropping systems already practiced in the dry zone and the effects varied with the type of intercrop and severity of heat and drought stress.*

INTRODUCTION

Climate change adaptation interventions will provide a buffer against economic risks brought about by climate change to decrease the economic vulnerability of coconut sector and increase the food security of consumers. The yield of plant species with reproductive structures of

agricultural importance is exceptionally sensitive to high temperature stress during flowering (Zinn *et al.*, 2010). Fruit set or abortion during early months after inflorescence opening is an important yield determinant factor in coconut (Peiris *et al.*, 1995). Initial fruit set can be reduced due to unfavourable environment factors such as temperature stress, low light conditions (low source strength) or water stress in perennial crops such as coconut (Kasturi Bai *et al.*, 2003; Thomas *et al.*, 2012) and oil palm (Legros *et al.*, 2009), and other fruit crops (Wubs *et al.*, 2009; Vara Prasad *et al.*, 2010). High number of flower and fruit abortion under high temperature is often observed in coconut plantations in the intermediate and dry zones of Sri Lanka (Ranasinghe *et al.*, 2012) even under irrigation (Nainanayake *et al.*, 2008). Therefore, it would be advantageous for plants to exhibit greater reproductive survivability at extreme temperatures and water stress. However, the degree of sensitivity and the pattern of reaction to environment stress may differ among cultivars / forms.

Development of heat and drought tolerant coconut cultivars has been recognized as a major adaptation measure to impacts of climate change. In many crops, reduction in pollen quality and adverse effects on pollination process have been identified as the principal deleterious effects of high temperature and water stress on fruit set (Wahid *et al.*, 2007). *In vitro* pollen germination at different temperatures (Reddy and Kakani, 2007) and field evaluation of cultivars for reproductive performance (Thomas *et al.*, 2012) has been used to select heat and drought tolerant crop varieties. However, quantitative information on heat and water stress impacts on pollen quality,

pollen germination, female flower production and fruit set and their variation with cultivars is scarce in coconut. Changing micro-climatic condition of coconut plantations is proposed as another adaptation strategy to improve reproductive survivability under projected climate change. Mixed cropping systems of coconut can bring about favourable changes in the micro-climatic conditions by influencing air temperature, VPD, soil moisture and soil temperature all of which will have a significant impact on modifying the reproductive and physiological performance, and subsequently, a sustainable productivity in coconut plantations. The present study aims to investigate the impacts of heat stress alone and both heat and drought stress on reproductive organ development and fruit set of coconut, identify the variation with cultivars and evaluate the capacity of coconut-based mixed cropping systems in improving the micro-climatic conditions and reproductive performance of coconut plantations.

MATERIALS AND METHODS

Experiment 1

Determination of the effect of heat stress on fruit set and related parameters

Experiment was conducted at the Maduruoya Genetic Resources Centre (MOSG) of Coconut Research Institute (CRI) using 16 palms (Tall x Tall cultivar, 25yrs) selected from two blocks according to the wetting pattern of the field. Number of new inflorescences opened, female flower production in each inflorescence, fruit set, of each developing bunch, percentage pollen germination and carbohydrate content (total soluble sugars and starch) of mature pollen and soil moisture percentage were collected monthly in 2011 and 2012. Climate data were recorded daily from the Agro-meteorology station at the MOSG.

Experiment 2

Determination of the effect of heat stress on fruit set and related parameters

Sixteen Tall x Tall palms (25-30 yrs of age) from *Wellawa, Kurunegala* (IL_{1a}) were used for the study. Monthly data on number of new inflorescences opened and female flowers produced, survival of female flowers in each developing bunch from pollination to maturity, percentage pollen germination and climatic parameters (daily) were collected in 2011 and 2012. Climate data of *Kurunegala* were used to study the response of reproductive performance to heat and drought stress.

Experiment 3

Screening coconut cultivars for high temperature tolerance by *in vitro* pollen germination

Pollen from seven cultivars of coconut; Tall x Tall (TT), Tall x San Ramon (TSR), Dwarf Green x San Ramon (DGSR), Dwarf Green x Tall (DGT), Tall x Dwarf Brown (TDB), Dwarf Brown x Tall (DBT), Dwarf Brown x San Ramon (DBSR) was collected from *Kurunegala* (IL_{1a}) in 2013. Ten palms per cultivar were used. Pollen germination (PG) was recorded after incubating pollen in an artificial growth media at pre-determined temperatures from 19°C to 39°C for 24 hrs. Three Microfuge tubes of each cultivar at each temperature treatment were used as replicates. Three microscopic slides with germination media with pollen were prepared from one Microfuge tube. Therefore, nine microscopic fields were used to analyze percentage pollen germination (%PG) of a cultivar at a given temperature. Maximum pollen germination recorded after 24 hrs of incubation, at each temperature was analyzed using bilinear equation. The optimum (T_{opt}), maximum (the highest temperature at which the PG is zero, T_{max}) and minimum (the lowest temperature at which the PG is zero, T_{min}) temperatures (cardinal temperatures) for pollen germination of different cultivars were determined according to Ranasinghe *et al.*, (2010).

Experiment 4

Effect of heat and water stress on fruit set and related parameters of different coconut cultivars

The cultivar evaluation trials maintained by the Genetics and Plant Breeding Division of CRI at *Wanathawilluwa* (DL₃, *Mawillu series* soils) and *Raddegoda* (IL_{1a}, *Melsiripura series* soils) were used to study the survival pattern of fruits in each bunch developed under different environment conditions. The palms were planted in 2004 (*Raddegoda*) and 2005 (*Wanathawilluwa*) and the flowering was started in 2007 (*Raddegoda*) and 2008 (*Wanathawilluwa*) (Therefore, the results are shown for young palms). The *Raddegoda* site is considered as a favourable site (near optimum conditions) for coconut cultivation and *Wanathavilluwa* site experiences heat and moisture stress for a considerable period within a year. Forms /crosses under evaluation were TT, TSR (Tall and Tall hybrids), DGSR, DGT (Dwarf Green and Tall hybrids) and TDB, DBT, DBSR (Dwarf Brown and Tall hybrids). Female flower production and their survival pattern from button nut stage to harvest-ripe stage were recorded monthly. Climate data of *Kurunegala* and *Puttlam* were used to study the response of reproductive performance of different cultivars to heat and drought stress.

Experiment 5

Evaluation of coconut-based cropping systems for changing microclimatic conditions and reducing vulnerability of coconut plantations to projected climate change

Two mixed cropping systems (coconut and guava, coconut and banana) and a monocrop (coconut) system in the *Anuradhapura* district (DL_{1b}) and one mixed cropping system (coconut and cashew) and a monocrop (coconut) system in *Puttlam* (DL₃) were used for the study. Air temperature at different heights of the palm, soil temperature (25 cm depth), soil moisture percentage (25 cm depth), female flower production, fruit set, rate of photosynthesis and Leaf Area Index of coconut were measured monthly.

RESULTS

Experiment 1

The variation of climatic factors (maximum temperature, vapour pressure deficit, rainfall and soil moisture percentage) in MOSG reveal that irrespective of the RF and irrigation, an 'atmospheric drought' was present during May to September in both years (2011 and 2012) in the experimental fields (Fig. 1).

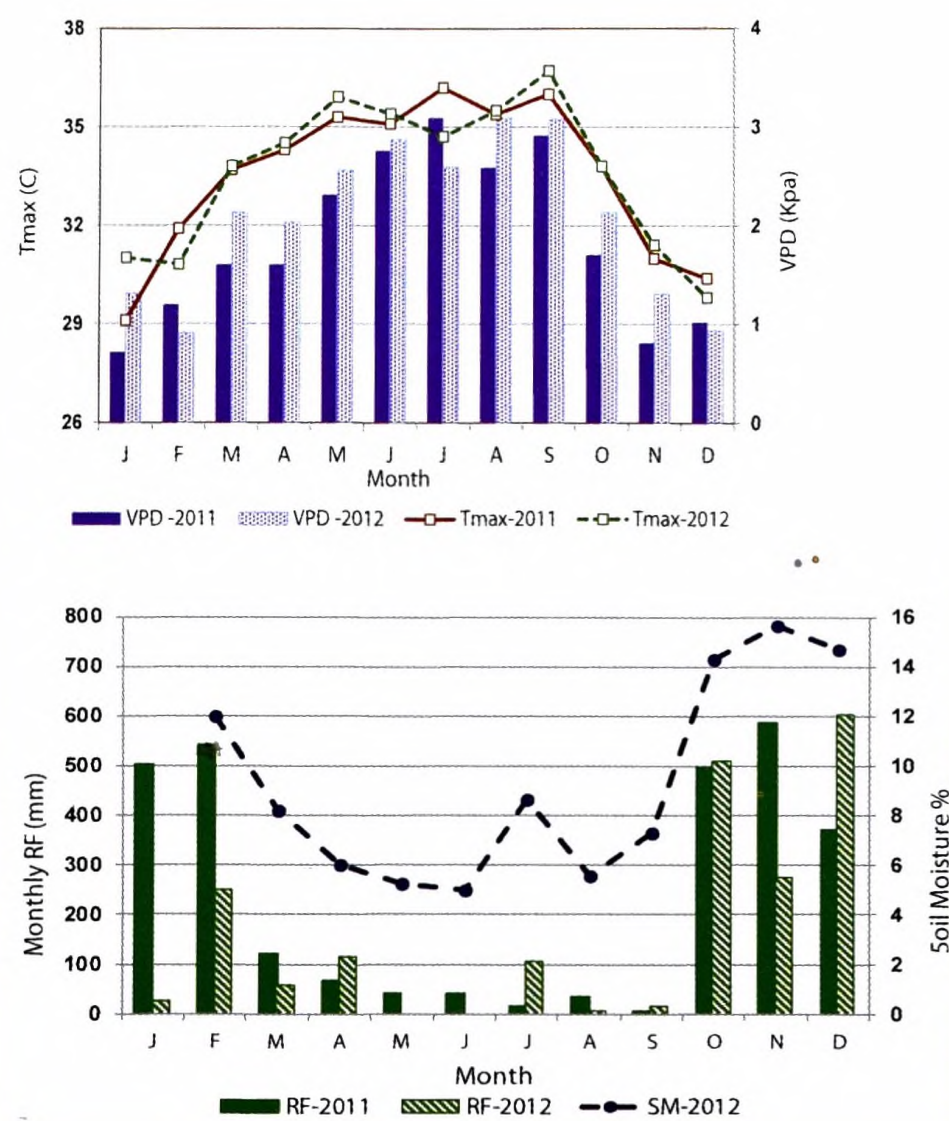


Fig. 1. Variation of maximum temperature (T_{max}), vapour pressure deficit (VPD) and rainfall (RF) in 2011 and 2012 and soil moisture percentage in 2012 in experimental fields

The female flower production was appreciably higher in the MOSG (92 and 82 FF / palm / month in 2011 and 2012 respectively) compared to other coconut growing areas in wet and intermediate zones (20-60 FF / palm / month), possibly due to warmer climate and higher solar radiation intensity in the Dry zone with irrigation during rain free period (Fig 2a). However, the female flower production in MOSG was significantly reduced during January to April in 2012 compared to 2011. Although there was a lower rainfall during this

period compared to 2011, the fields were under irrigation (the soil moisture percentage was 6%), therefore, the reasons for reduction in FF production during first quarter of 2012 has to be further studied. The number of set fruits did not follow the same trend as female flower production showing the overriding effect of heat stress and high VPD on fruit set (in the absence of water stress) (Fig 2b). Although the female flower production was highest in the inflorescences opened during June to September period, the fruit set was lowest during July to September when the monthly mean of maximum VPD was greater than 2.5 kPa and T_{max} was higher than 35°C possibly attributing to the impaired pollen germination process on the stamina (Snidder *et al.*, 2011)

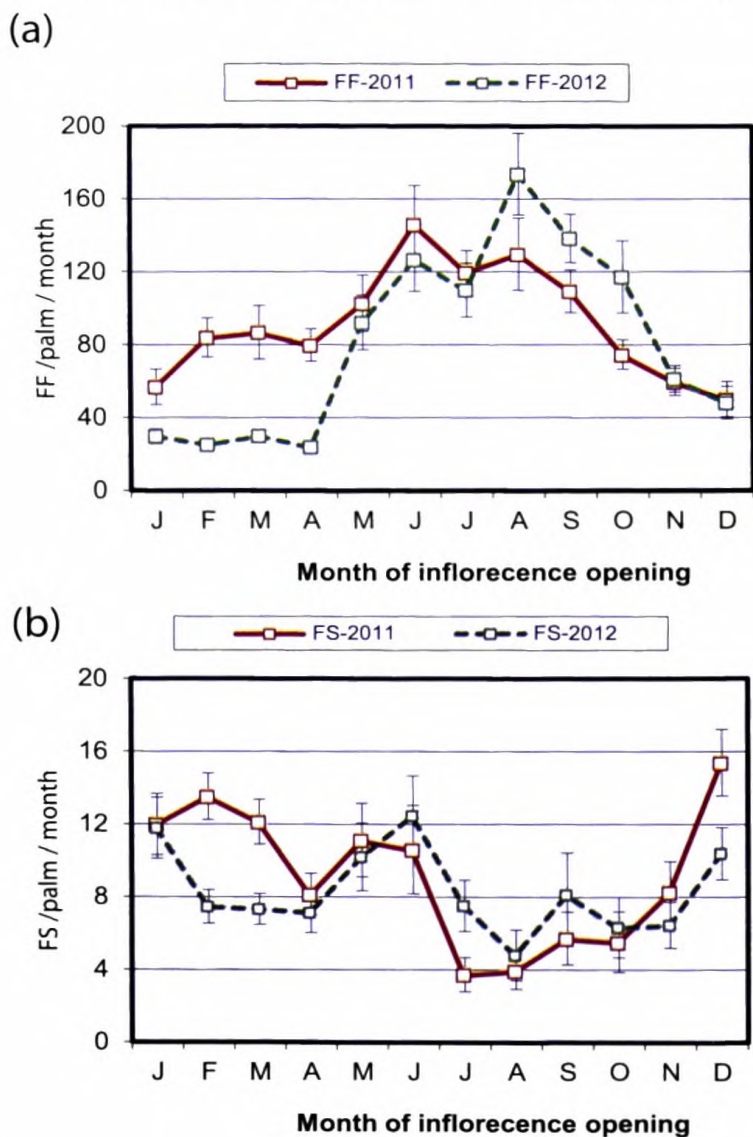


Fig. 2. Monthly variation of female flower production (FF) (a) and fruit set (FS) (b) of inflorescences opened from January to December 2011 and 2012 at MOSG.

The germination ability of pollen (quality) was less than 20% in the inflorescences produced during March to June and December in both years, October (2011) and September (2012) and it increased during July to August, even with high

VPD and T_{max} (Fig. 3). The variation in total soluble sugars (TSS) of pollen followed the same pattern as the % pollen germination (Fig. 4a) and pollen starch content did not vary much with time except during last three months of a year (Fig. 4b)

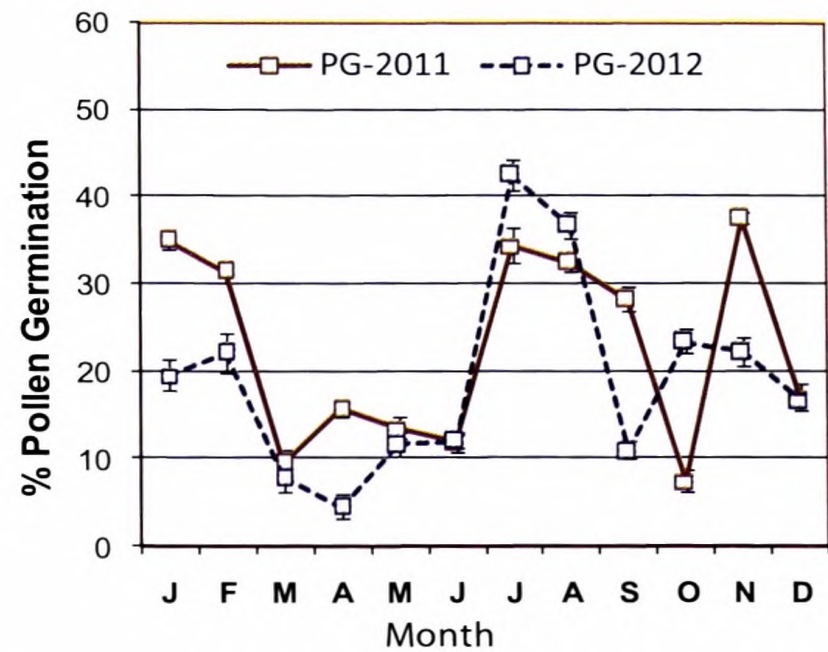


Fig. 3. Monthly variation in pollen germination (pollen quality, %PG) of inflorescences opened from January to December in 2011 and 2012 at MOSG.

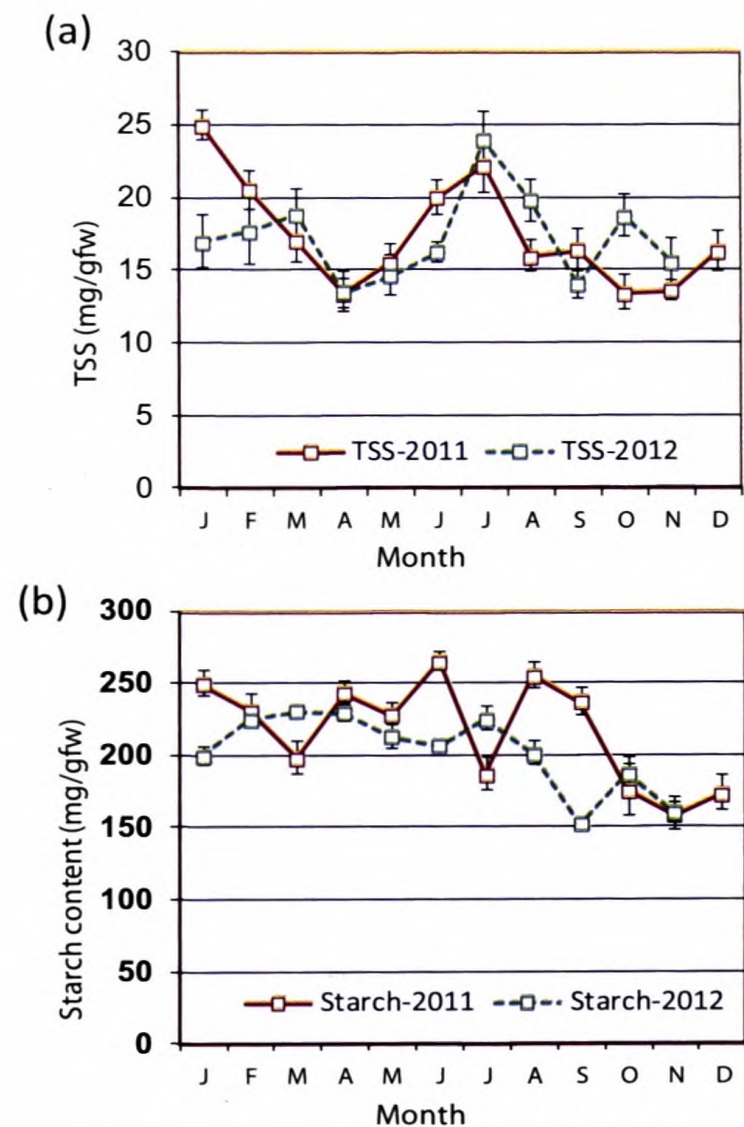


Fig. 4. Monthly variation in total soluble sugars (TSS) (a) and starch (b) in pollen of inflorescences opened from January to December in 2011 and 2012 at MOSG.

Experiment 2

Monthly female flower production was lower in 2012 compared to 2011 and the difference was significant only in May, July and September (Fig. 5a). However, the fruit set at three months stage was consistently and significantly lower than that of 2011 during May to September 2012 (Fig. 5b). The results showed a very high potential for a yield reduction in 2013, specially from March to July (2nd, 3rd and 4th picks) compared to that of 2012.

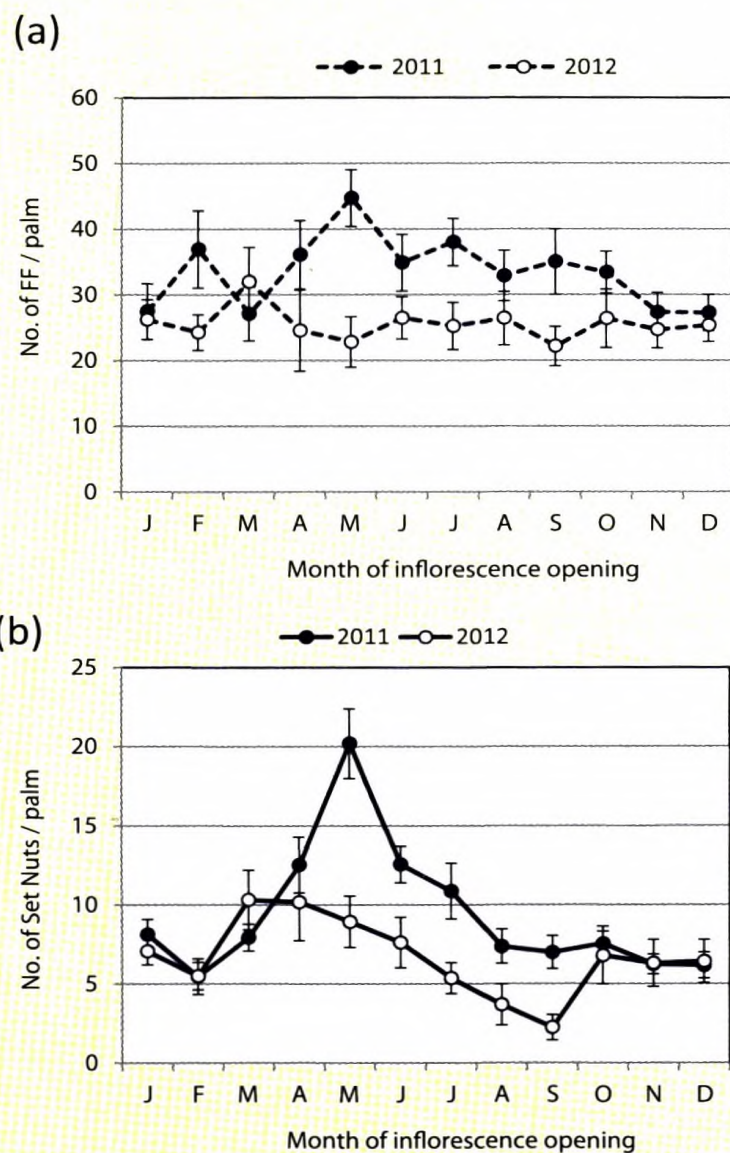


Fig. 5. Female flower production (FF) (a) and fruit set (at 3-month stage) (b) in IL1a site in 2011 and 2012.

Experiment 3

The minimum (T_{min}), optimum (T_{opt}) and maximum (T_{max}) temperatures for *in-vitro* pollen germination varied among cultivars. T_{min} ranged from 15°C (TSR) to 17.5°C (DGSR) with an average of 16.7°C, T_{opt} ranged from 27.5°C (DGT) to 30.2°C (DBT) with an average of 28.3°C and T_{max} ranged from 37.5°C (DBT) to 41°C (DGT) with an average of 39.2°C (Table 1). Among seven cultivars tested, DGT exhibited the widest temperature range ($T_{max} - T_{min} = 24.5°C$) while DBT had the smallest

temperature range ($T_{max} - T_{min} = 21°C$) even though the latter cultivar showed the highest T_{opt} .

Table 1. Cardinal temperatures for pollen germination of seven coconut cultivars

Cultivar	Cardinal temperatures(°C)		
	T_{min}	T_{opt}	T_{max}
TT	17.0	28.9	40.0
TSR	15.0	28.2	39.0
TBD	17.1	27.5	38.4
DBT	16.5	30.2	37.5
DBSR	17.3	28.3	38.5
DGSR	17.5	28.0	39.8
DGT	16.5	27.5	41.0
Mean	16.7	28.3	39.2

Experiment 4

The T_{max} of *Kurunegala* district was greater than 33°C in March, April, May and October and these values were higher than the values for *Puttlam* during the same period. Due to the failure of North-East Monsoon rains in 2011 and South-West Monsoon rains in 2012 there was a severe drought condition in July, August and September period of 2012 in both areas (Fig. 6).

The female flower production (number/ palm /month) was reduced during January to June 2012, due to prevailed heat and drought drought in both sites (Fig. 7). Although it was improved in IL_{1a} site during the last six months in 2012 with the onset of rains, it was noticeably low in DL_3 site in 2012 even under the best soil condition.

The survival rates of the fruits of bunches produced in every month were monitored monthly, and the survival curves for two selected months based on rainfall and temperature (May 2012 and August 2012) are shown below for both sites (Fig. 8). The inflorescences opened in May 2012 were naturally exposed to severe drought conditions prevailed in August and September in their 4th and 5th month of development and inflorescences opened in August 2012 were naturally exposed to the same drought conditions in their 1st and 2nd month of development. For the

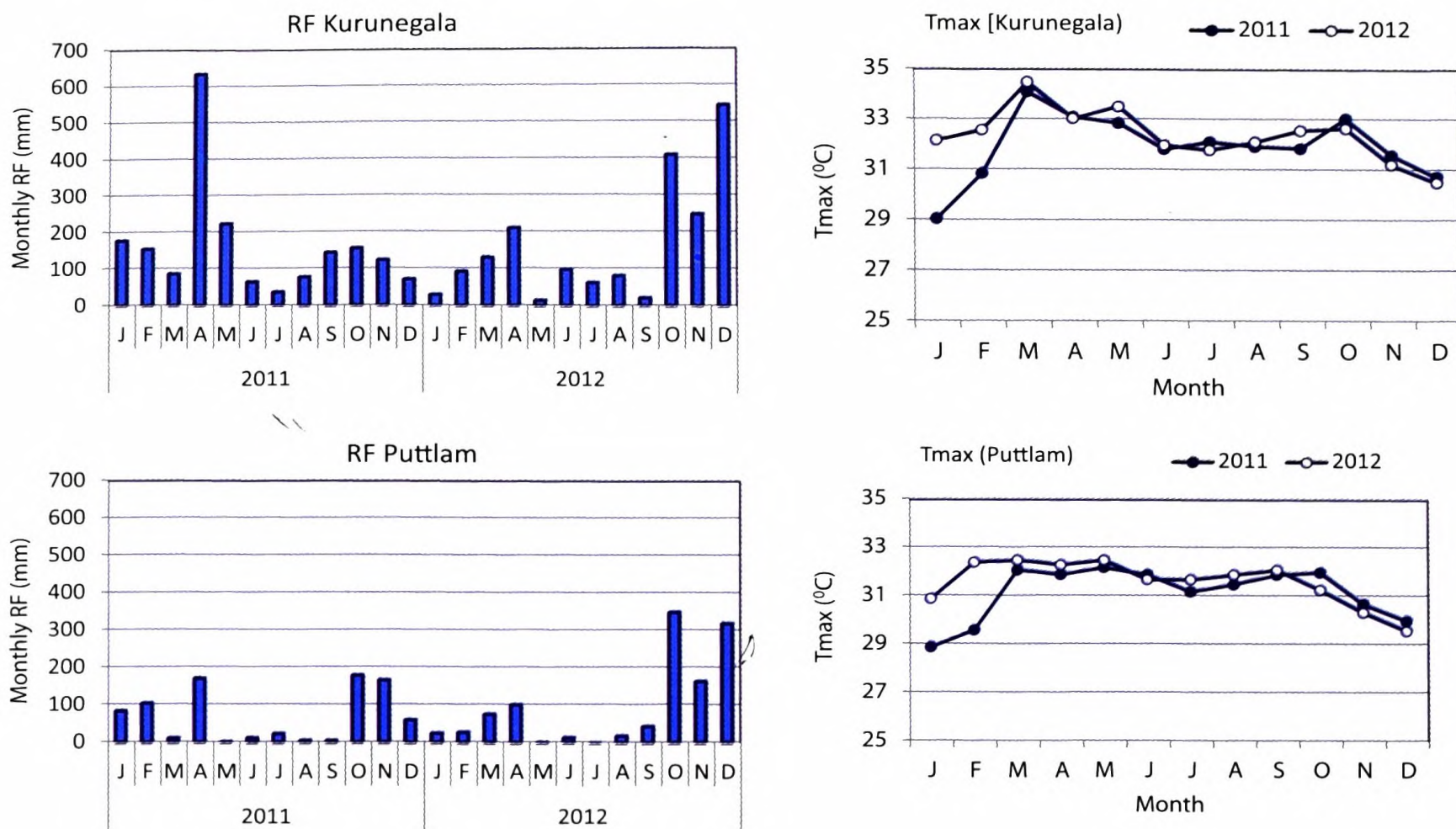


Fig. 6. Variation in monthly rainfall and mean T_{max} in *Raddegoda (Kurunegala, IL_{1a})* and *Wanathavilluwa (Puttalam, DL₃)* in 2011 and 2012.

inflorescences opened in May 2012, DGSR and DGT outperformed other crosses followed by DBT with respect to reproductive survivability in most favourable site (IL_{1a}) whilst DGT was the best performer in heat-prone site (DL₃) (Fig. 8 a, c). For the inflorescences opened in August 2012, reproductive survivability of all the cultivars was greater than TT cultivar in most favourable site (IL_{1a}) and it was almost zero in all the crosses even on the best soil class (Block 3) in the heat-prone site (DL₃) (Fig. 8 b, d).

Experiment 5

In the coconut/cashew mixed cropping system in DL₃, the air temperature at coconut canopy level during pollen dispersion time (9.00-10.00) was lower in compared to mono crop during March to July and it was opposite in February (Fig. 9 a). During noon (11.30-12.30), the air temperature at coconut canopy level was lower in mixed cropping system compared to coconut mono crop system only in July and it was opposite in February and March (Fig. 9 b).

The soil temperature (soil T) in the manure circle of coconut palms (MC) and at the centre of square near cashew plants (CS) at 25 cm depth was

measured in the morning, noon and afternoon. The mean soil T was almost always lower in the coconut /cashew mixed crop system (C+C) compared to monocrop (C) (Fig. 10 a, b). This effect was very significant in the CS. The soil moisture percentage (% SM) in the manure circle of coconut palms (MC) and at the centre of square near cashew plants (CS) at 25 cm depth is given below (Fig. 11 a, b). In the CS, soil moisture percentage was always lower in the mixed cropping system compared to mono crop system indicating a possible competition for soil moisture in the mixed cropping system.

The rate of leaf photosynthesis of both systems reduced drastically after April due to drought and recovered from November onwards following rains (Fig. 12 a). The Leaf area index of coconut palms (LAI) was always lower in mixed cropping systems compared to monocrop system again indicating a competition for resources (Fig. 12 b).

Although there was a sharp decline in fruit set of both systems over the time in 2012 due to prevailed drought condition, the recovery of coconut palms following rains was faster in mixed cropping systems compared to the mono crop system (Fig. 13).

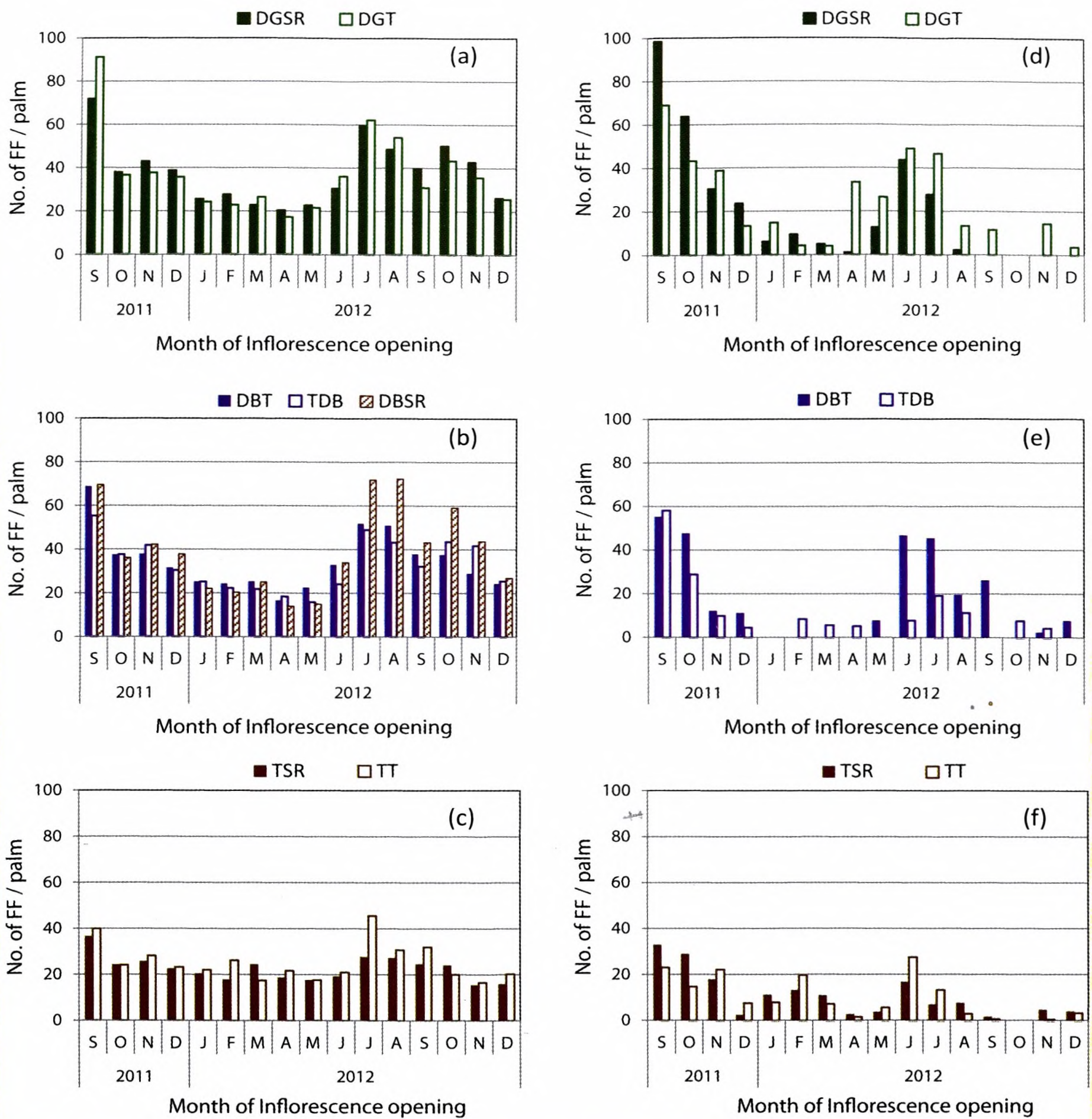


Fig. 7. Production of female flowers in DG and Tall hybrids (a, d), DB and Tall hybrids (b, e) and Tall and Tall hybrids (c, f) in *Raddegoda* (IL_{1a}) (a, b, c) and *Wanathavilluwa* (DL₃) (d, e, f) from September 2011 to December 2012.

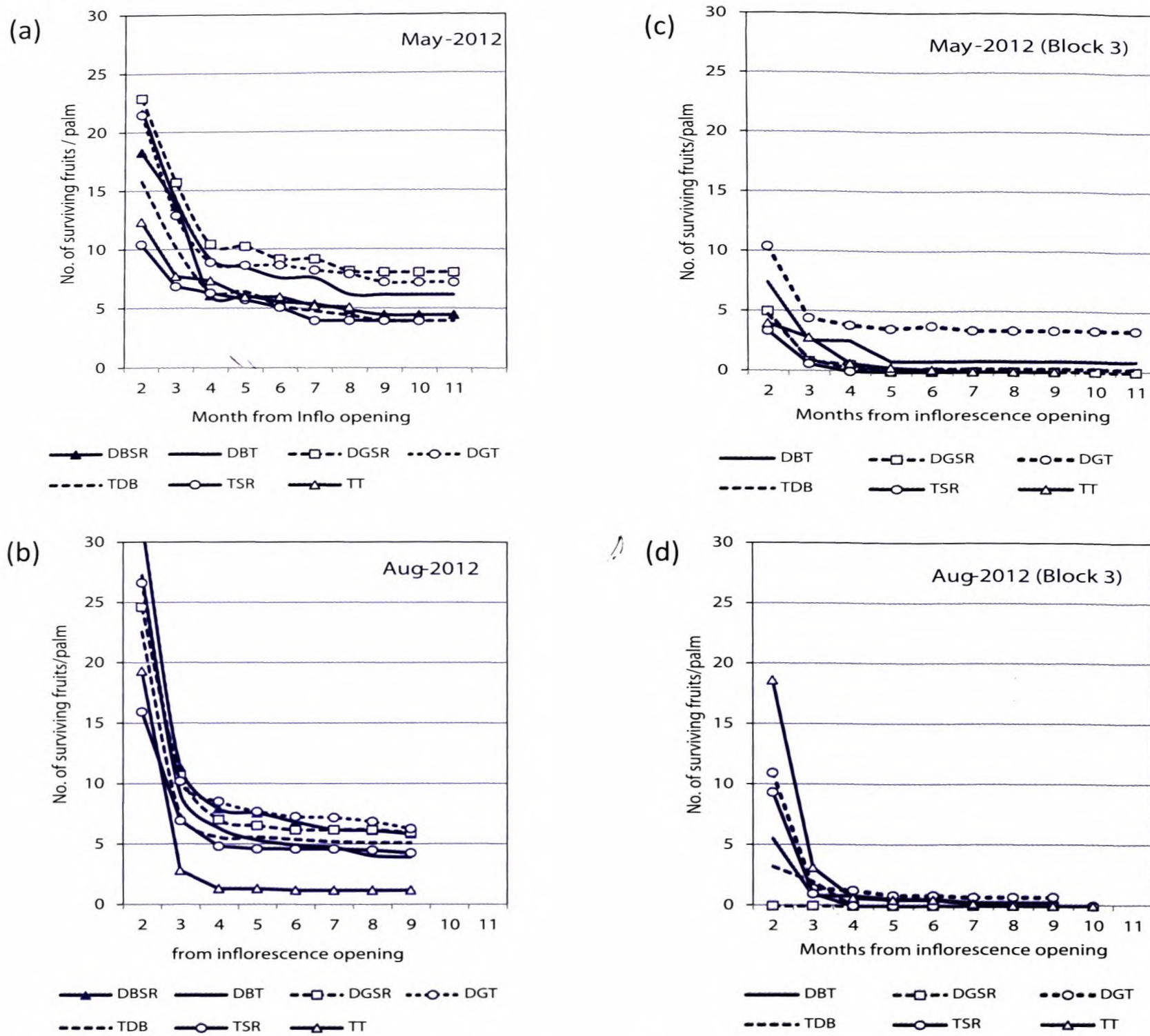


Fig. 8. Survival of fruits of the inflorescences opened in May 2012 (a, c) and August 2012 (b, d) in *Raddegoda* (IL_{1a}) (a, b) and *Wanathavilluwa* (DL₃) (c, d). The survival of fruits from 2nd month onwards from opening is shown.

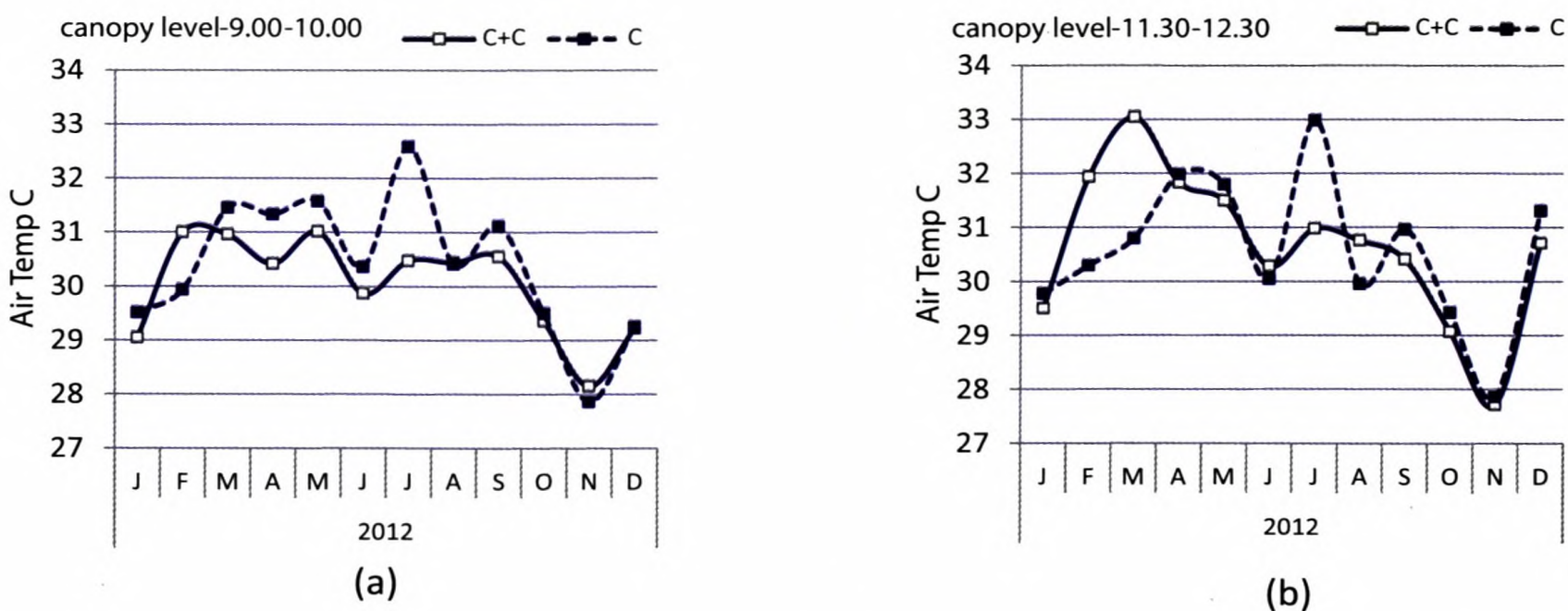


Fig. 9. The variation in air temperature at canopy level in coconut and cashew system (C+C) and coconut monocrop system (C) in the morning (9.00-10.00) (a) and noon (11.30-12.30) (b) in *Puttalam* (DL₃) in 2012.

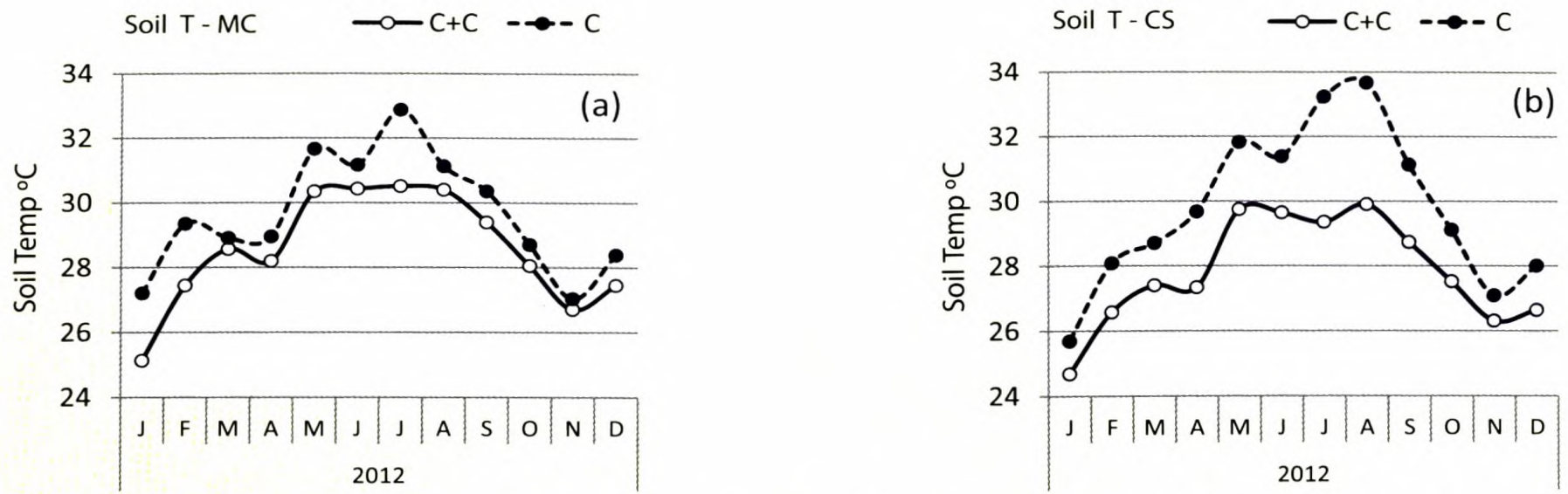


Fig. 10. Variation in soil temperature in the manure circle of coconut palms (MC) (a) and at the centre of square (CS) (b) at 25 cm depth in coconut and cashew system (C+C) and coconut monocrop system (C) in Puttalam (DL₃) in 2012.

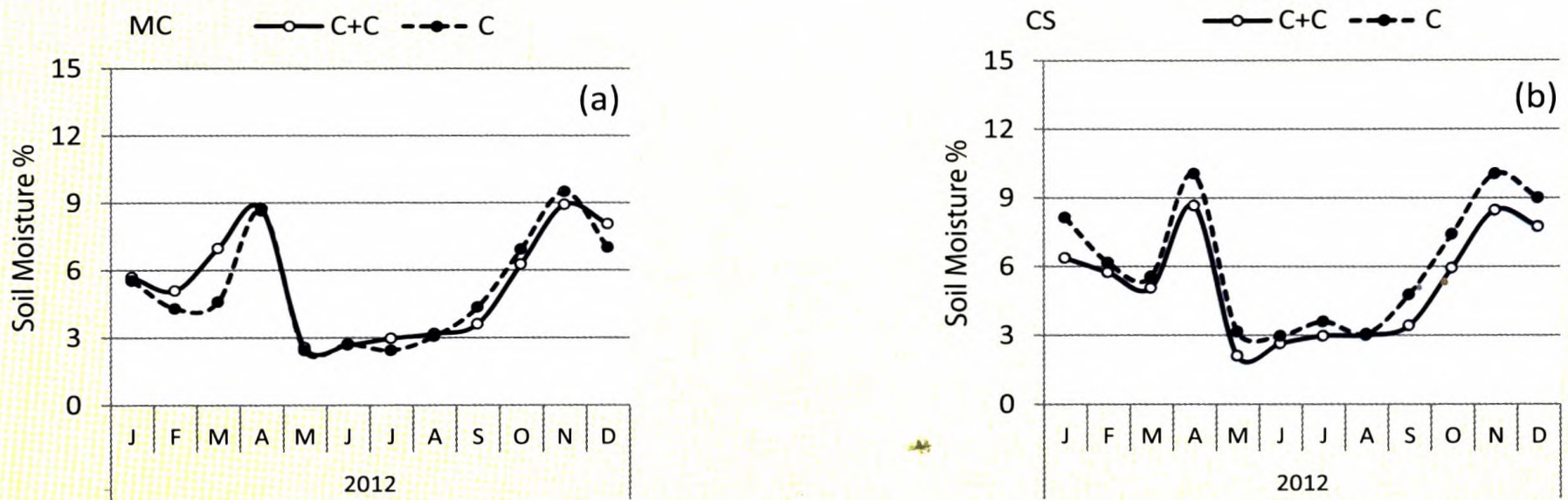


Fig. 11. Variation in soil moisture percentage (% SM) in the manure circle of coconut palms (MC) (a) and at the centre of square near cashew plants (CS) (b) at 25 cm depth in coconut and cashew system (C+C) and coconut monocrop system (C) in Puttalam (DL₃) in 2012.

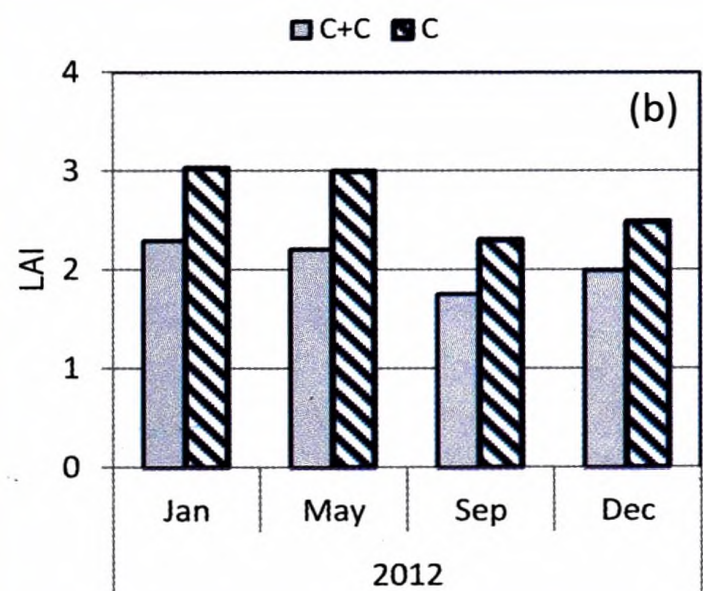
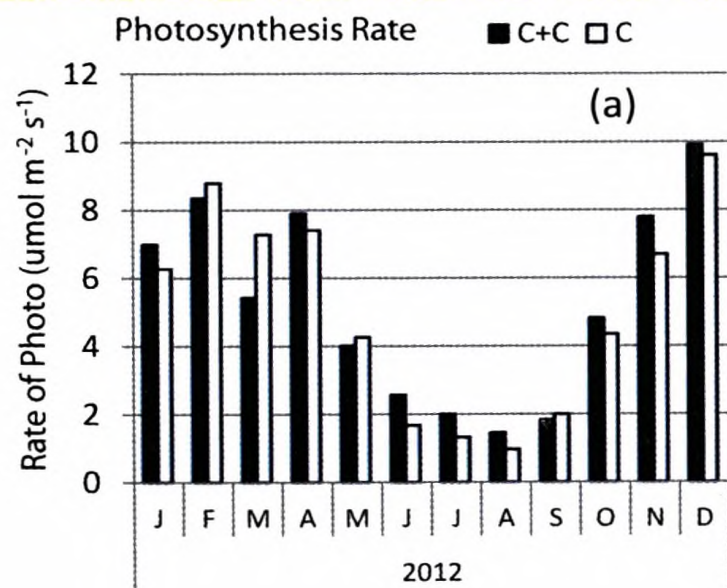


Fig. 12. Rate of photosynthesis (a) and leaf area index (LAI) (b) of coconut palms in coconut and cashew system (C+C) and coconut monocrop system (C) in Puttalam (DL₃) in 2012.

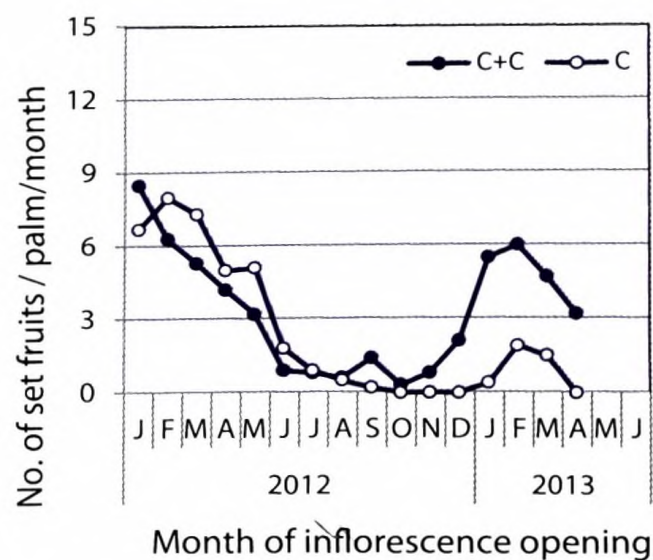


Fig. 13. Fruit set (number / palm / month) of coconut palms in coconut and cashew system (C+C) and coconut monocrop system (C) in *Puttlam* (DL₃) from January 2012 to April 2013.

Similar micro climatic data were collected at mixed cropping systems in *Anuradhapura* site (DL_{1b}) with coconut + Guava, coconut + banana and coconut monocrop systems. The number of fruit set / palm / month in both mixed crop systems was greater over the period compared to mono crop system irrespective of time (Figs. 14 a and 14 b).

DISCUSSION

The overall results of the experiment on heat stress impacts on fruit set revealed that the pollination process is highly sensitive to atmospheric drought (heat stress and high VPD) even in the absence of water stress (under irrigated conditions). The critical temperature (T_{max}) and VPD for pollination process and fruit set of irrigated plantations were 35°C and 2.5 kPa, respectively. Female flower production (number) and quality of pollen was less sensitive to heat stress and high VPD in the absence of water stress. For TT cultivar, the critical temperature for fruit set under both heat and water stress was 33°C (Ranasinghe *et al.*, 2012) and fruit set of an inflorescence/s opened in a given month (number of set fruits/palm/month) was negatively correlated with number of high temperature days ($T_{max} \geq 33^\circ\text{C}$) during first three months of inflorescence opening and total reproductive dry matter requirement of a palm during month of inflorescence/s opening (first month) whilst it

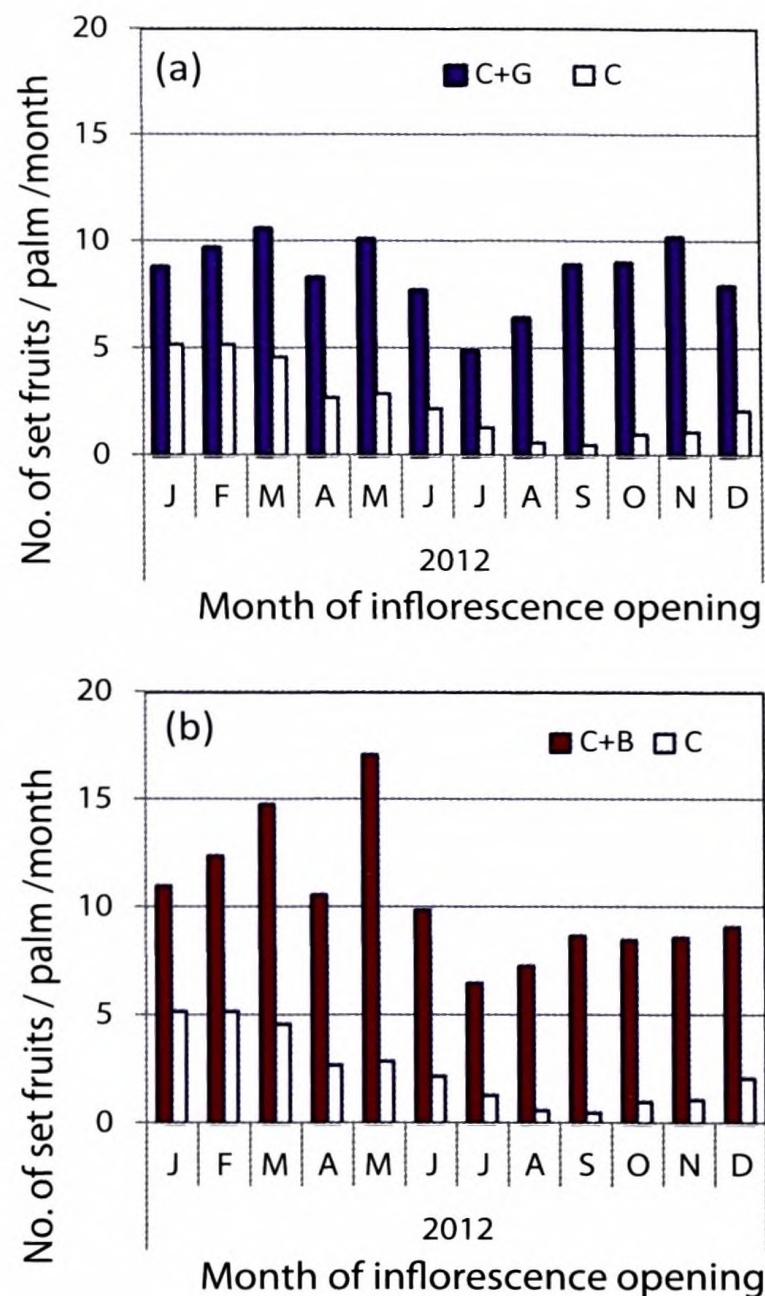


Fig. 14. Fruit set (number / palm / month) of coconut palms in coconut and Guava (C+G) system (a), coconut and banana (C+B) system (b) and coconut monocrop (C) system in *Anuradhapura* (DL_{1b}) from January 2012 to April 2013.

positively correlated with number of female flowers produced in the inflorescence/s. Under field conditions, heat and drought is normally experienced simultaneously by both male and female reproductive structures but heat and drought stress can have different effects on the development of male and female reproductive structures before inflorescence opening. Previous studies suggest that when high temperature stress is placed separately upon male and female gametes prior to pollination, pollen is often the most vulnerable (Zinn *et al.*, 2010). For instance, in tomato, the reduction in fruit set under moderate heat stress was mostly due to a reduction in pollen quality and germination and this was mainly attributed to the disruption of sugar metabolism and proline translocation

during the male reproductive development (pollen formation) few days before anthesis (Sato *et al.*, 2006). Heat stress can reduce carbohydrate deposition in pollen grains (Zinn *et al.*, 2010). The sex determination, formation of pollen mother cells and formation of pollen by meiosis of coconut take place four months, two months and three to four weeks before inflorescence opening, respectively (Perera, 2010). In wheat, heat stress during the period of microspore meiosis induced tapetum degradation. This degradation of the nutritive tissues of the tapetum leads to pollen sterility (Zinn *et al.*, 2010). In addition, high temperatures can cause poor anther dehiscence characterized by tight closure of locules, which was shown to reduce pollen dispersal in rice and tomato and it can shorten the receptive period of stigma in female flowers, and thereby decrease the chances for a successful pollination (Hedhly *et al.*, 2005). Therefore, further studies are needed to investigate the effects of drought stress (heat and water stress) on quality of female flowers at the receptive stage (carbohydrates) and quality of mature pollen (carbohydrates and viability) and their differential impacts on fruit set and yield components in coconut.

The cardinal temperatures for *in vitro* pollen germination varied among seven cultivars tested and DGT exhibited the widest temperature range suggesting wider temperature adaptability compared to other cultivars. Complementing the observation, DGT performed better than other crosses following exposure to moderate drought under field conditions in most favourable site (IL_{1a}) and also in the heat-prone site (DL₃). The recovery rate of the same tested cultivars following a severe drought, with respect to female flower production and fruit set, has to be further studied. The relationship between reproductive performance and the factors influencing it other than heat and drought stress (total source strength, leaf area index development, total dry matter requirement of reproductive organs) are also being assessed. The quality of button nuts at the receptive stage (carbohydrate availability) and quality of pollen at the mature stage (carbohydrates and germination ability) of seven cultivars and their variation with respect to heat and water stress will be

determined in detail for identifying the drought tolerant cultivars. Further, the cardinal temperatures found in the present study has to be validated with the pollen collected during different seasons of the year for consistency and used to develop a heat tolerance index for coconut. This index can be used to identify coconut cultivars suitable for high-temperature prone areas. In addition, the identified cardinal temperatures and response functions can be incorporated into process-based coconut models.

Regarding the use of coconut based mixed cropping systems for changing the micro climatic condition of the plantations, although some modifications of micro climatic condition in the coconut mixed cropping systems were observed, since 2012 was an extreme year with respect to heat and water stress, the effects of mixed cropping systems on reproductive performance and related parameters of coconut has to be tested further before coming to a conclusion. Therefore, the data collection will be carried out for another two years before making a recommendation. Mixed cropping systems that can improve the microclimate and yield of coconut plantations in the dry zone will be identified as an adaptation strategy for coconut plantations to impacts of climate change.

CONCLUSIONS

The study has identified critical temperatures for irrigated and non-irrigated coconut plantations, with respect to pollen germination and fruit set. The identification of heat and drought tolerant cultivars and mixed cropping systems for the dry zone is progressing.

ACKNOWLEDGEMENTS

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